A Ph.D. SYNOPSIS

in the area of

Artificial Intelligence

on the topic

Unified Cooperative Enactive Social Cognitive Artificial System for Solving Real World Problems

submitted by

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Under the Supervision of

Prof. D. K. Chaturvedi

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Contents

1 Introduction **2**

1.1 Motivation . . . 2
1.2 Artificial Social system and Conscious Social agents . . . 3
1.3 Artificial Social Knowledge and memory system . . . 4
1.4 Cognitive Architecture framework for Artificial Enactive social system 4
1.5 Tools for Implementation of Enactive Social Cognitive System . . . 4

2 Literature Review **6**

2.1 History of Artificial Cognition . . . 6
2.2 Cognitivist Approach . . . 6
2.3 Emergent Approach . . . 8
2.3.1 Connectionist system . . . 8
2.3.2 Enactive system . . . 9
2.4 Hybrid Approach . . . 9
2.5 Artificial Conscious System . . . 10
2.6 Cognitive Architecture . . . 10
2.6.1 SOAR . . . 11
2.6.2 EPIC . . . 12
2.6.3 ICARUS . . . 13
2.6.4 ACT-R . . . 14
2.6.5 CLARION . . . 14
2.6.6 KISMET . . . 15
2.6.7 ICUB . . . 16

3 Proposed Work **18**

3.1 Problem Statement . . . 18
3.2 Scope of the thesis . . . 19
3.3 Objective of the thesis . . . 19
3.4 Methodology . . . 20
3.5 Thesis outline (Tentative) . . . 20
3.6 Outline of Proposed Work . . . 21

References **22**

1

Introduction

The thesis aims to show that individual agents in an artificial enactive social system can solve real world complex tasks by conscious, unified, cooperative service. The enactive individual agents can organize and interact with each other in an artificial society having homogeneous values and goals based on respective knowledge and experience as performed by human agents in society. Human society are organization composed of individual. The living entities perform core tasks in collective approach to reach the goal. The tasks are completed by dedicated cooperation and coordination of individual agents under the organization management. The tasks whether it is in the interest of an individual or for society requires knowledge. The complete knowledge is managed by the society for its smooth function and is known as societal knowledge.Therefore the first and primary focus of the research is to develop an artificial knowledge management system for processing flow of information in the organization of enactive agent based society; which addresses issues like identification acquisition, storage, retrieval and representation for solving complex problems. The second focus of the thesis in order to achieve primary goal is to have an artificial social memory system which ensures to provide relevant knowledge based on learning to the required agent so that his task could be completed at right time with correct level of knowledge and information.The third focus to achieve the second one, i.e. to have such cognitive artificial memory system, an architecture has to be developed which ensures to provide flow of information to the agent so that his task could be completed in a distributed but in integrated approach. The fourth focus for completing third one is to build a tool (combination of software and hardware) so that interaction between agents can be establish where they can share knowledge for solving individual as well as group task.

1.1 Motivation

Motivation for the thesis was to develop enactive social agent system and improve the design develop by the Icub group. Enactive humanoids like icub are capable to solve complex problems using their individual learning and knowledge. These robots can be given a next level of cognition with communicative behaviour of sharing knowledge and helping each other to solve task. Individual enactive agent may tend to be in some problems in uncertain events. In such condition there can

be solution provided by social agents. These solution can be fast and accurate to fulfil the needs of a particular agent. This feature is adapted by many biological agents in solving uncertain real complex problem. In today's world, intelligent agent works on algorithms which interpret sensors data and activate actuators giving desired output. These types of agents developed are partially autonomous and need controller to work in open system. The second type of agents are cognitive agents which behave as autonomous agents. These agents are able to solve some level of uncertainty under there own knowledge and experience, but under high degree of uncertainty in the free environment they are unable to adapt and take decision to complete the task. To overcome the above two agent's problems, in this thesis social agents are proposed to be developed that can work in real world uncertain environment using communicative behaviour in a social system with unified, cooperative services.

1.2 Artificial Social system and Conscious Social agents

In an artificial social society, social agents are the entities which communicate with each other. These social agents have common behaviour and operate at individual level, bilateral level and collective level. The conscious social agents exist in a shared environment and cooperate with each other to improve the performance, effectiveness and easiness to reach the goal. Therefore these conscious social agents can be designed to work individually but their actions can be controlled under some legal foundation to have mutual cooperation and coordination. Such type of agent collection under restriction is called as an artificial social system. To design such artificial social system special architecture has to be designed solving critical issues like, how these social agents will self organize and interact with each other. How these social agent will form the complex growing network with distributed and decentralized agents. How these social agents will share knowledge and regulate other social agent action. Lastly, how the system efficiency, control, reliability and stability could be maintained. All these critical issues is taken in the thesis and solution for each question with practical approach will be answered.

1.3 Artificial Social Knowledge and memory system

The issues discussed for artificial social system can be solved by developing artificial social knowledge and memory system. In cognitive system the agents develop knowledge in their own limited skill learning frames and store the skill knowledge in a memory for further use. On the social context the knowledge is considered in a collaborative way where each social agent can use the knowledge from other agents which is beyond the scope of a particular agent for problem solving. In the thesis a social knowledge and memory management is proposed to be developed that is able to have a unique knowledge base different from current cognitive system. This knowledge management system will manage the Knowledge of all social entities.

1.4 Cognitive Architecture framework for Artificial Enactive social system

Cognitive architecture framework are becoming the preferred possibility to process different views of cognition like attention, memory, problem solving and learning. These cognitive architecture help to integrate all artificial behaviour mentioned above on one platform and perform the task accordingly without ignoring anyone. Through cognitive architecture it is possible to model system that can be applied to wide range of task. In cognitive architecture due to presence of attention and memory, it is possible to have learning and use to develop knowledge for solving problems. These type of architecture so far developed in artificial system fails when problems become complex and uncertain considering environment as a part. In this thesis a novel architecture is proposed for enactive social system based on unified cooperative service. This architecture is a meta social cognitive architecture to solve the problems with the help of social agent.

1.5 Tools for Implementation of Enactive Social Cognitive System

The architecture discussed above is to be implemented for the real time purpose based on display and graphical interface with multimedia interaction. Also the interface is to be designed with cognition, perception and motor action. The above general computer driven cognitive tools lack in social interaction. In the thesis to

achieve this social interaction goal web based, database driven with administrative control cognitive tool is proposed. The net framework is capable of having social interaction, SQL database is having capability of dynamic memory storage and security option that will control the social agent.

2

Literature Review

2.1 History of Artificial Cognition

Cognitive system is having the roots in Artificial intelligence which started in 1945 by the concept that how it is possible to build a machine which is capable of thinking like humans [Bus45]. A step forward was taken in 1950 with Turing test [Tur50] as a measure of machine intelligence. Strachey, 1952 [Str52] gave the concept of non mathematical programming by giving the thought that the mathematical part of the program take more instructions and efforts in comparison to non mathematical operations. So machine intelligence can be implemented by logical programming. In 1956 Darmouth College Summer AI conference the name, Artificial Intelligence was first coined by McCarthy defining "AI is the science and engineering of making intelligent machines, especially intelligent programs [CMRS55]. Samuel, 1959 [Sam59] developed the first artificial game playing program for checkers which defeated a known human player. This was the first application in the field of artificial intelligence. Devol, 1961 [Dev61] obtained the first U.S. robot patent named as Unimate. The first version of Unimate industrial robot is installed in a die casting machine. Unimation's industrial robot, Unimate worked on a General motor auto-mobile assembly line. So artificial intelligence based cognitive system was established and a new field for developing intelligent system having capability of human took a new step forward. From the starting of establishment of Cognitive system, it was broadly classified into two classes: *Cognitivist Approach* based on symbolic system and the *Emergent Approach* holding connectionist, dynamical and enactive system. Cognitivist approach is viewed as information processing in terms of symbols, rationals, encapsulation, struture and algorithms. On the other hand Cognitive system as emergent approach is viewed as self organizing and dynamical system. In the modern cognitive system both cognitivist approach and emergent approach are combined together and is known as Hybrid approach.

2.2 Cognitivist Approach

Newell, 1959 [NSS59] developed a digital computer program known as General Problem Solver(GPS). It was used to solve intelligent problem using heuristics.

McCarthy, 1960 [Car60] developed programming system known as LISP for IBM704 computers. It was used to instruct machine with declarative and imperative sentences which provide common sense for implementing instructions. Weizenbaum, 1966 [Wei66] developed ELIZA a program running on Mac OS. It was used to have natural language conversation between man and computer. Minsky, 1967 [Min67] published his international book "Finite and Infinite Machine" which explains finite machines are neural network. Newell, 1972 [NS72] in his book "Human problem solving" gave the concept of information processing system based on symbolic structure to solve elementary logic, chess and puzzle. Minsky, 1975 [Min75] gave the concept of frame which is a data structure for representation of stereotyped situation forming in it as network of node and relation. The collection of related frames are linked together in a frame system. This frame system has the capability of producing knowledge and information. Newell, 1976 [NS76] gave the concept of physical symbol system which is a collection of pattern and process. In these pattern and process are organized in a structure can result in system to behave intelligently. In Newell's and Simon's 1976 paper, two hypotheses are presented.
1) The Physical Symbol System Hypothesis: A physical symbol system has the necessary and sufficient means for general intelligent action.
2) Heuristic Search Hypothesis: The solutions to problems are represented as symbol structures. A physical-symbol system exercises its intelligence in problem-solving by search, that is, by generating and progressively modifying symbol structures until it produces a solution structure.
The first hypothesis states that any system showing general intelligence is based on physical symbol and physical symbols organized in structure representing general intelligence. The second hypothesis states that system based on symbols gets in solution of the problem by heuristic search. Schank and Abelson, 1977 [SA77] gave the concept of scripts. A script is a structured representation describing a stereotyped sequence of event in a particular context. Scripts are used in natural language understanding system to organize a knowledge base in terms of the situation that the system should understand. The work done by Newell [NSS59, NS72, NS76, New90], Simon [NS76], Mc. Carthy [CMRS55, Car60], Minsky [Min67, MP69, Min75, Min86] and Schank established the classical cognitivist approach and afterward many architecture were build with applications to verify it.

2.3 Emergent Approach

2.3.1 Connectionist system

Founder of both cognitivism and connectionism Mcculloch, 1943 [MP43] found that neural events can be defined in terms of propositional logic. The net behavior can be defined in terms of addition of complicated logical expression satisfying these condition. Rosenblatt, 1958 [Ros58] proposed perceptron model which explained that the pattern classification can be implemented by perceptron neural network if the pattern can be represented by binary numbers. Minsky and Papert, 1969 [MP69] described and implemented perceptrons in solving memory and learning problems resembling a brain like construction. The perceptron learning theorem was proved and shown its importance in linear separation problem.Grossberg's, 1976 [Gro76] developed Adaptive Resonance Theory(ART) for pattern classification using feature extraction from the object as input.ART used both unsupervised and supervised learning for classification and prediction. McClelland, 1981 [McC81] gave a breakthrough in giving a method that can develop generalizations for retrieving of specific objects or events with previous experience stored in memory using neurons. Kohenen, 1982 [Koh82] developed a self organizing learning process based on neural network topological maps in which proximate points on the maps are mapped to the network states resembling input points to be close together having close weights. Once the mapping is completed kohenen network is used for pattern classification. Hopfield, 1982 [Hop82] implemented the first complete recurrent network which acts as an content addressable memory for pattern recognition. Feldman and Ballard, 1982 [FB82] described the advantages of generic connectionist model over symbolic model. The advantage of these connectionist model was based on issues like stability, noise sensitivity, distributed decision making, time and sequencing problem and representation of complex problem. Rumelhart and McClelland, 1986 [RMG86] gave the concept of parallel distributed processing which is based on neuron model. This supported classical connectionism and implementation of real time brain in artificial system using multi neuron, known as back propagation neural network. The BPN network are able to solve non linear separable problem which was not possible with perceptron network. Hinton and Sejnowski, 1986 [HS86] developed Boltzmann machine network which is a variant of recurrent network, having stochastic weight updates repeatedly to determine global minima and not stuck in local minima during learning process. Fodor, 1988 [FP88] studied the difference between classical and cognitive architecture.They gave the concept that structured and symmet-

ric neural architecture can provide better learning and knowledge in favour of connectionism. Moody and Darken, 1989 [MD89] proposed Radial Basis Network which is a fast learning local unit network with Gaussian as its activation function. Radial Basis Network has high performance, better learning and representation. Elman, 1990 [Elm90] developed Elman nets which is a another recurrent network having hidden layers with better representation capability.

2.3.2 Enactive system

Maturana, 1970 [Mat70] was the pioneer for starting enactive system research in his work Biology of Cognition. The main focus of his research was to start autonomous, social and cognitive system based on autopoiesis which explains that system emerges due to the process of self organization where an entity develop by self using systematic arrangements. Maturana and Varela, 1980 and 1987 [MV80][MV87] defined the enactive system with three types of instict behaviour due to autopoietic nature, ontogenetic behaviour due to development of the system in lifetime and communicative behaviour due to interaction with its member entities of the society. Brooks, 1991 and 1999 [Bro91, Bro99] developed behaviour based robots having human like brain with enactive agents principle of thinking. The entity robots emerges as dynamic and skill interactive agents with the environment. For development of enactive cognition system sensor and motor action simultaneously leads to perception by an entity agent. According to Hurley, Regan and Noe [Hur98, OA01, Noe05], enactive learning is only possible when their is a coordination between sensors, motors and action agents in an entity. Thompson, 2007 [Tho07] gave five important components necessary for enactive cognition system. These five components are living being are autonomous, the nervous system is an autonomous dynamical system, Cognition is the exercise of skilful know how in situated and embodied action, the world of the agent is not a pre specified external realm, represented internally by the agent brain, but is a relational domain "brought forth" by the agent autonomy and coupling with the environment.

2.4 Hybrid Approach

Cognitive process are generally heterogeneous where some of the process are best explained by symbolic model while other are explained by connectionist model [DD87]. The advantage of symbolic model includes better representation, detailed processing steps and high accuracy of result. The connectionist model have the advantages like parallelism, learning capabilities and fault tolerance. Somensky, 1988 [Smo87] proposed hybrid system involving conceptual processing and sub

conceptual processing. Conceptual processing used provide high level of representation, public access and reliability. On the other hand sub conceptual process gives capability like skill and intuition fitting in connectionist model. On this basis steps for hybrid system was laid down and latter many hybrid models were proposed by scientists [Sun94, Sun95, AL98].

2.5 Artificial Conscious System

The artificial consciousness [Den71, Den82, Den84, Den91, KON95, Kit99, Res01] in a system is determined by the following behaviour given as reactiveness, rationalism, attention, executive, emotional, self awareness, emphatic and socialism. The social behaviour is an important parameter to produce consciousness in the artificial system where each agent synchronize in superposition and play an orchestra to reach a singular unified solution for achieving the goal [HP95, HP96].

2.6 Cognitive Architecture

Cognitive architecture are created in order to form systems to behave and act like human beings in uncertain environment. Allen Newell, 1990 [New90] gave major criteria that should be present in a cognitive system for its evaluation. These criteria are broadly classified as:

- Adaptive behaviour
- Dynamic behaviour
- Flexible behaviour
- Development
- Evolution
- Learning
- knowledge integration
- Vast knowledge base
- Natural language processing
- Real time processing
- Brain realization

The architecture so far designed and implemented are classified into three main groups known as symbolic(cognitivist), emergent and hybrid systems. The major properties that are the base of any cognitive architecture are memory and learning. Memory makes a repository for knowledge base of the system and responses from outer world. Learning on the other hand is the process of shaping the knowledge which it retrieves from its perception and action phenomenon. Higher level of properties are added in the above system with learning and memory to make the system more reliable and robust. These properties are intelligence, self organization, reasoning, planning and socialism etc. The symbolic architecture are based on processing of symbols or declarative knowledge with analytical and inductive learning. Emergent architecture are based activation signals of low level that flows through network of several processing unit with associative and competitive learning. Hybrid architecture results due to combination of symbolic and emergent approach. The symbolic architecture works on the flow of information as physical symbols, having the capability of input,storage and output in the memory for knowledge formation and retrieval. The symbol entities are encoded and form a graph, frame and scripts based relationship through analytical and inductive learning. Many architecture are developed on this basis and are given as:

2.6.1 SOAR

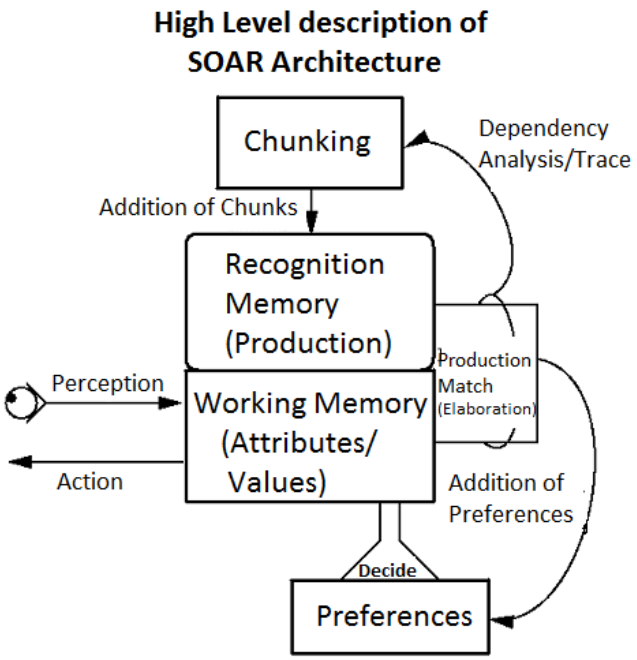

Figure 2.1: SOAR architecture from SOAR usermanual 6.0(Source:[LRN87])

SOAR [LRN87, JTLR93, LHH91, LCAD93, LLN91, LHJ+90, RLNM91] stands for (State Operator and Result): SOAR is a rule based symbolic architecture designed to have the capability of general intelligence. SOAR framework is a knowledge based system which stores its knowledge in the form of physical symbolic rules connected by operators. SOAR represents all the task as collection of problem space. The problem space are made up of a set of states and operators that change the behaviour of the state. SOAR take an initial state from the problem space and then try to reach the final state in order to achieve the goal of the task. SOAR perform decision cycle to move from initial state to any current state. If the decision cycle reach an impasse, a situation where no progress is possible because of disagreement, SOAR the select another problem space with required information about it.

SOAR has two memories known as Recognition memory which is a production system having set of rules and condition given by perception and its action relation. Production system match the pattern with the working memory to perform the action. Production's in the long term memory places the preferences like accept, reject, better, worse etc. into the preference memory. This preference memory decides which attributes or values should enter or leave the working memory. The SOAR work in two phase elaboration phase and decision phase and it is repeated until the goal is reached. The decision phase decides whether any preferences are in the preference memory or not and then choose the next entity like problem space, state , operator or goal.Learning in SOAR is done through chunking mechanism. Chunking is an explanation based learning, when a decision cycle returns a result (if a sub goal is achieved) to the super goal a new production is created whose elements are tested with action has returned preference , and then stored in Recognition memory in form of chunks.

2.6.2 EPIC

EPIC [KM97, KWM97, KMMS99, MK97a, MK97b, SLG+99] stands for(Execute-Process/Interactive Control): Epic is a cognitive architecture developed for modelling human multi-modal and multiple task performance. EPIC architecture is made up of components like motor processors, cognitive processor and perceptual processor. EPIC is developed to have a base and benchmark for perceptual motor action, cognitive analysis skill and task solving capabilities. EPIC architecture central part is having a production system and working memory in a cognitive processor connected with all perceptual and motor processors. EPIC has a generative task model with production rules giving procedural knowledge of the task.

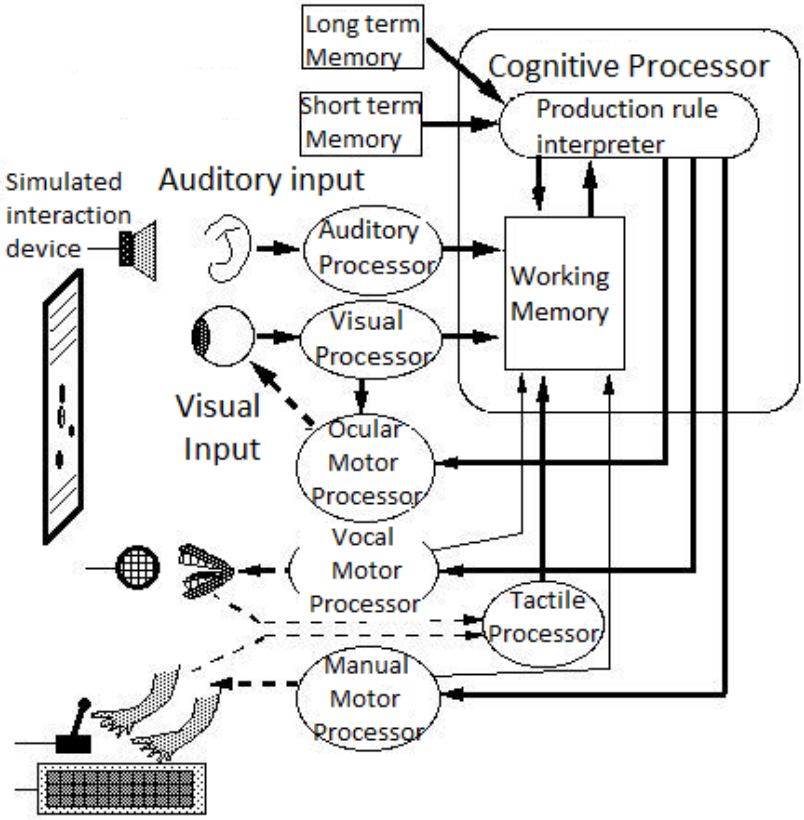

Figure 2.2: EPIC architecture (Source:[MK97a, MK97b])

When EPIC interacts with a task environment then the information flow from the perceptual processors to the cognitive processor having production rule interpreter and working memory. These develop the action signals which finally goes to the motor processor for completing the response for the task. The Information flow is represented in the figure.

2.6.3 ICARUS

ICARUS[LMA+91] was developed to have artificial system with capabilities of human like problem solving, reasoning and skill acquisition. ICARUS divides memory into conceptual memory and skill memory which form two types of knowledge that are concept and skill knowledge.

Concept knowledge contain three components given as Perceptual buffer, long term conceptual memory and belief memory. The perceptual buffer contains the data from the perceptual sensors. Long term conceptual memory contains several structures of concepts and its relation. Belief memory consist of conceptual instance which agent belief to be correct.

Skill knowledge also contains three components given as Motor buffer, Long term

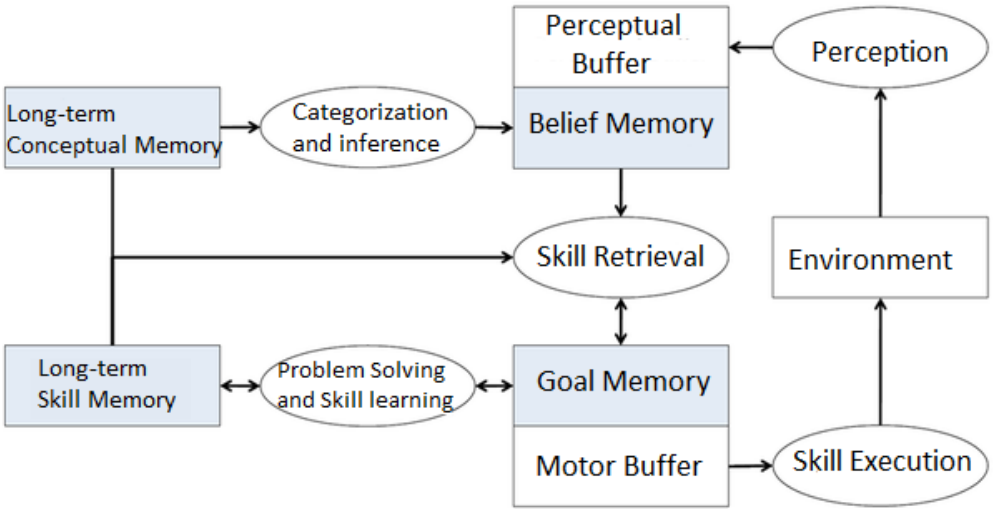

Figure 2.3: ICARUS Architecture (Source:[LMA+91])

skill memory, Goal memory. Long term skill memory contains generalized structure of skills, that agent has to perform in the environment. Goal memory contains high level goals that agent trying to achieve and also skill instances that help to achieve the goal. Therefore in the ICARUS architecture, first the concepts are developed and then skills are implemented.

2.6.4 ACT-R

ACT-R [AB73, And76, And83, And90, AS91, And93, AM97, ABLM98, AL98, ABB+04, And07] stands for (Adaptive control of thought- Rational): ACT-R is a modular cognitive architecture which has integrated modules that produce synchronize cognition. ACT-R modules are having their own process described as : Visual module for finding the objects, Manual module for controlling the body through motors. ACT-R has four temporary storage buffer for module communication with each other. The declarative module is for obtaining information from long term memory, Intentional module keeps the track of internal states during problem solving. The central and the main component is the production system which performs matching , selection and execution of productions based on symbolic and connectionist structure.

2.6.5 CLARION

CLARION [SPS01, Sun06, Sun07] stands for (Connectionist Learning with Adaptive Rule Induction Online): CLARION architecture is developed to have a human mind system inside the artificial system. CLARION is an integrated architecture which have subsystem inside it. There are four subsystems known as ACS, NACS, MCS and MS. ACS(action centred subsystem) whose role is to control actions like

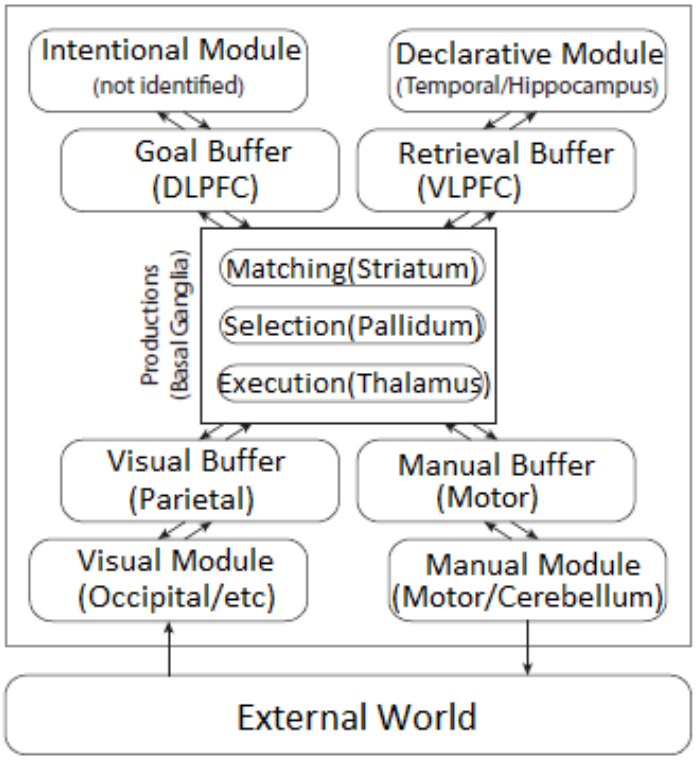

Figure 2.4: The organization of information in ACT-R 5.0 Information in the buffers associated with modules is responded to and changed by production rules. The names in parentheses indicate the corresponding part of the human brain. DLPFC = dorsolateral prefrontal cortex; VLPFC = ventrolateral prefrontal cortex. (Source:[ABB+04])

external body movements and internal computational operations. NACS (Non Action Centred Subsystem) is to maintain knowledge of the complete cognitive system. MS (Motivational Subsystem) is to provide motivations for perception, action and cognition. MCS (Meta Cognitive Subsystem) is used to monitor, modify and direct operations of ACS.

2.6.6 KISMET

The kismet [Bre00, Bre03] is a robot having a head with 21 degrees of freedom. It is having high level processing of face expression with human interaction. Kismet emotional expression are fear, anger, disgust, joy, sorrow, surprise, boredom, interest and calm. Kismet cognitive architecture has five modules given by perceptual system, emotion system, behaviour system, drive system and motor system. Kismet is an hybrid architecture with both cognitivist rule base action and connectionist learning.

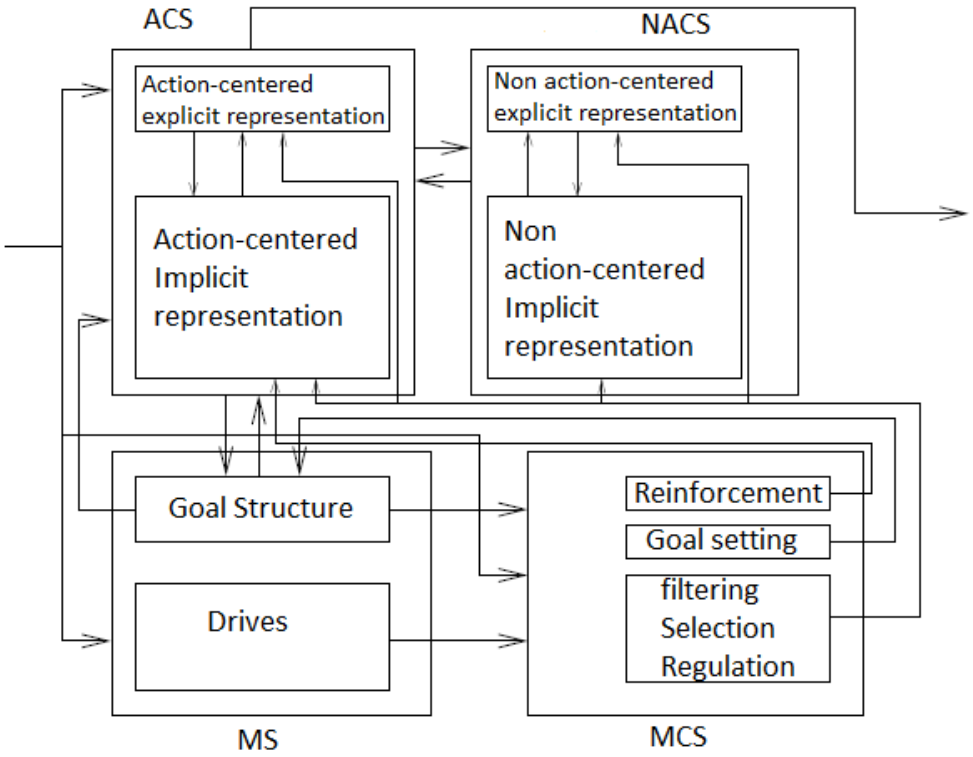

Figure 2.5: CLARION (Source:[SPS01])

2.6.7 ICUB

ICub [GMV07] is an enactive cognitive system based artificial humanoid with 53 degree of freedom. The iCub architecture is a three layer architecture: iCub embedded system, software architecture, and cognitive architecture. Embedded system include DSP processor, hub and gigabit ethernet line for communication between internal and external world. Software architecture is having YARP(Yet Another Robot Platform) is a multi platform open source framework that provide robot control using application program interface. The cognitive architecture has three levels: phylogenetic for sensorimotor primitives, ontogenetic primitive for visual motor mapping and anticipation of goal states, prospective primitive for actions.

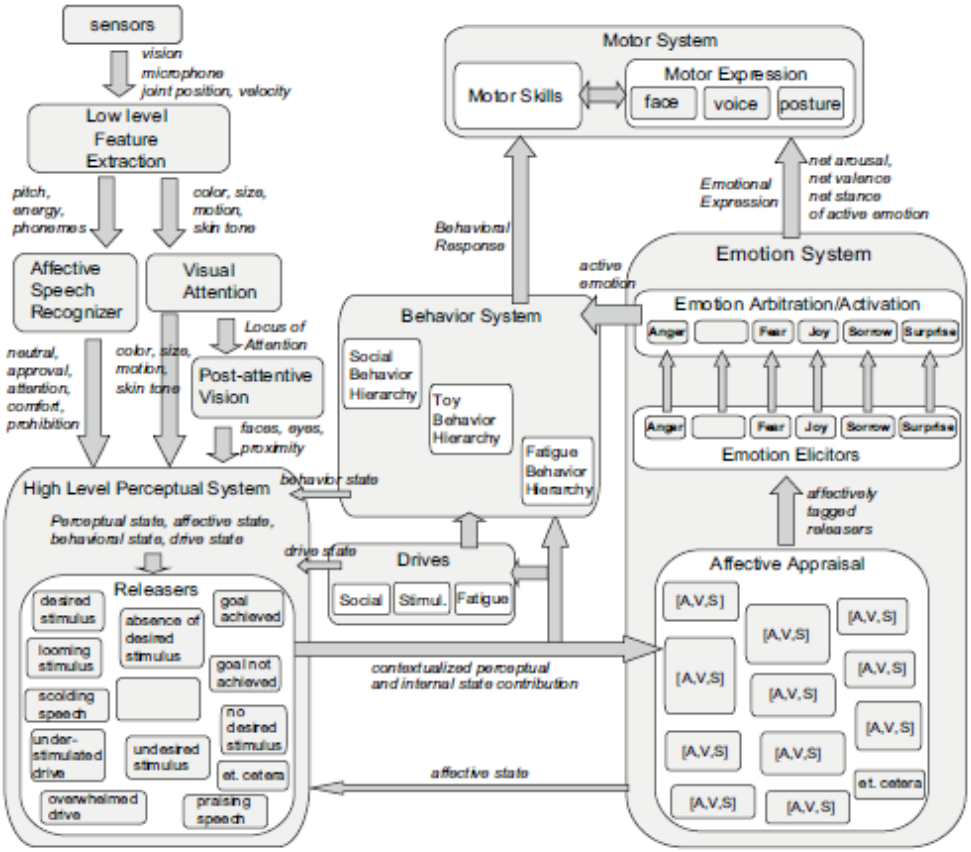

Figure 2.6: An overview of Kismet's cognitive architecture. (Source: [Bre03])

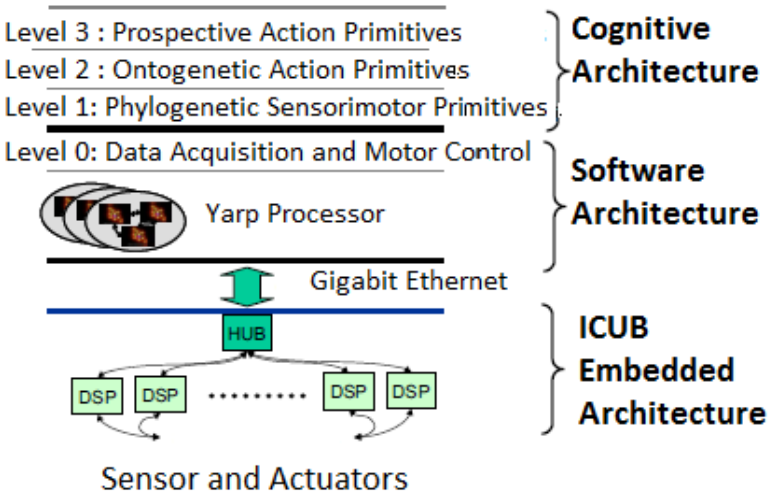

Figure 2.7: Layers of ICUB architecture (Source:[GMV07])

3

Proposed Work

According to the historical evidence Artificial Intelligence(AI) and Artificial Cognitive System works to know engineering and understanding of human intelligence. In current modern scenario both AI and cognitive system took advance steps in developing theories, models, architecture and some applications for achieving the goals and is still on the same path. In this work, it is suggested that using the current methods and standards it is not possible to develop and have progress in artificial human intelligent system. So the current cognitive system require advance methodological innovation to achieve the goal. Today's cognitive scientist are attempting to know the depth of human cognition and create artificial intelligent system with human intelligence. They are not considering some key and critical issues in designing artificial system to achieve the goal of having human intelligence.

3.1 Problem Statement

1. First and foremost human being are social living beings. They solve there problems by taking help, cooperation and consultation with each other. In this work artificial system is proposed which focus on having social system with unified, cooperative, conscious services.

2. The second issue is that the knowledge human beings develop is through sharing and learning under some controlled legal restrictions. In the same way the proposed artificial system must have a shareable knowledge base and management system which will coordinate to help each other.

3. Thirdly the human system are regulated under the architectural framework where they integrate all the models like cultural, social, intelligence, knowledge, memory, perception, attention and action under one framework and then they survive to achieve the goals. So the proposed artificial system will have an integrated architecture framework considering all the above models and then solve the problems.

4. Fourth issue is that human is an embodied, enactive system with physical,socialize and communicate with each other. Hence it is very necessary for the artificial system to be embodied, enactive and social, so that we can

have social agents under one goal and objective and work with their own intelligence and experience. For this purpose a combination of software and hardware tools have to be design and developed in this proposed work so that we can have the artificial social cognitive agents and system.

3.2 Scope of the thesis

Social cognitive system is an emerging field with vast aspects still to be explored. It is important to present the scope of the work. There are several specific regions to target in context to social agents and its system. Rather than focusing on certain possibilities, the thesis deals with enactive social cognitive system as the general topic for research viewed on basis of system approach. The thesis primary focus is on system design and implementation at physical layer, abstract layer and knowledge layer moulded in a communicative layer, considering an holistic approach for social cognitive architecture. So the thesis target over embodied system, learning system, memory system, knowledge system and communicative system for social agents in the proposed cognitive architecture.

3.3 Objective of the thesis

The primary objective of the work is to develop social agents and artificial enactive social system in order to complete the task that requires agents to distribute functionalities to each other . In this context, the core research objectives of this thesis are

1. To define the concept of social agent and artificial enactive social cognitive system.

2. To study how to develop a conscious knowledge management system of a distributed enactive social agents for given task under set of resources and environment.

3. To develop an architecture framework for the artificial cognitive social system.

4. To design and build a methodology for the artificial social system in order to achieve the solution for the autonomous social system.

5. To implement the design using hardware and software system, to develop unified cooperative consciousness based enactive social cognitive system .

3.4 Methodology

The research problem is oriented towards the goal of developing social autonomous agents with the ability to interact and help the world with its experience and knowledge. All cognitive system are developed to have artificial human like mind with the ability of perception and action. So a systematic step by step process is developed in order to achieve the mentioned objectives. So the step by step methodology includes Designing, developing, implementing and representing the software and hardware system for social agents. Validating the system design to check that the software and hardware engineered meets the specification and purpose of developing social agents. Testing the system for the quality and services of the software and hardware, so that it fits the requirement.

3.5 Thesis outline (Tentative)

The thesis chapter outline is a tentative plan which may change as the work proceeds.

- Chapter 1 is the introductory chapter. It introduces with motivation of doing the research work, problem statement, scope of the project, brief overview and proposed work.
- Chapter 2 includes a literature review which covers, history of artificial intelligence, progress of artificial intelligence toward cognitive system, theories of artificial cognitive system, architecture in artificial cognitive system and its applications.
- chapter 3 presents the definition and concept of the social agents and artificial conscious social system covering the primary objective.
- Chapter 4 presents the methodology for the development of architecture framework on which basis the design of the social system will be implemented.
- Chapter 5 shows the experimental stage for implementation of both hardware and software design for unified cooperative enactive social system considering all models defined in the architecture.
- Chapter 6 provides a discussion and summary of the thesis major findings. Also it gives the future plans for the progress of social system.

- At last Appendix provide the important steps involved in design of the enactive social system.

3.6 Outline of Proposed Work

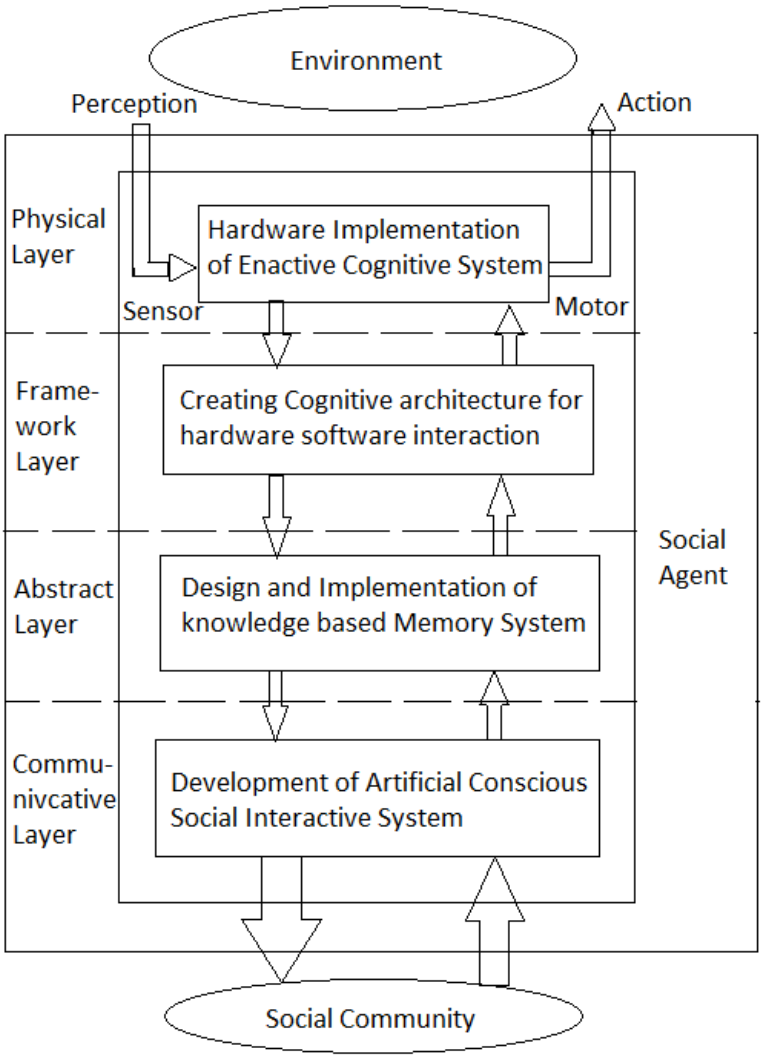

Figure 3.1: Outline of Proposed Work

References

[AB73] J. R. Anderson and G. H. Bower. *Human associative memory*. Washington, DC: Winston and Sons, 1973.

[ABB+04] J. R. Anderson, D. Bothell, M. D. Byrne, S. Douglass, C. Lebiere, and Y. Qin. An integrated theory of the mind. *Psychological Review*, pages 1036–1060, 2004.

[ABLM98] J. R. Anderson, D. Bothell, C. Lebiere, and M. Matessa. An integrated theory of list memory. *Journal of Memory and Language*, 38:341–380, 1998.

[AL98] J. Anderson and C. Lebiere. *The Atomic Component of Thought*. Lawernce Erlbaum Associate,Mawah,N.J., 1998.

[Alb97] J. S. Albus. The nist real time control system (rcs): An approach to intelligent system research. *Journal of Experimental and Theoritical Artificial Intelligence*, 9:157–174, 1997.

[AM97] J. R. Anderson and M. P. Matessa. A production system theory of serial memory. *Psychological Review*, 104:728–748, 1997.

[And76] J. R. Anderson. *Language, memory, and thought*. Mahwah, NJ: Lawrence Erlbaum Associates, 1976.

[And83] J. R. Anderson. *The architecture of cognition*. Cambridge, MA: Harvard University Press, 1983.

[And90] J. R. Anderson. *The adaptive character of thought*. Mahwah, NJ: Lawrence Erlbaum Associates, 1990.

[And93] J. R. Anderson. *Rules of Mind*. Hillslade, NJ : Lawrence Erlbaum Associates, 1993.

[And07] J. R. Anderson. *How can the human mind occur in the physical universe*. New York, NY: Oxford University Press., 2007.

[AS91] J. R. Anderson and L. J. Schooler. Reflections of the environment in memory. *Psychological Science*, 2:396–408, 1991.

[Baa97] B. J. Baars. In the theater of consciousness: global workspace theory, a rigorous scientific theory of consciousness. *Journal of Consciousness Studies*, 4:292–309, 1997.

[Bre00] C. L. Breazeal. *Sociable machines: expressive social exchange between humansand robots*. PhD thesis, Massachusetts Institute of Technology, Massachusetts, 2000.

[Bre03] C. L. Breazeal. Emotion and sociable humanoid robots. *International Journal of Human-Computer Studies*, 59(1-2):155, 2003.

[Bro91] R. A. Brooks. Intelligence without representation. *Artificial Intelligence*, 47:139–159, 1991.

[Bro99] R. A. Brooks. *Cambrain Intelligence: The Early history of the New AI*. Cambridge, Mass: Bradford Books, 1999.

[Bus45] V. Bush. As we may think. In *The Atlantic Monthly(Boston)*, volume 1, pages 101–108. Boston, 1945.

[Car60] J. Mc. Carthy. Recursive functions of symbolic expression and their computation by machine. *Communication of the Association for Computing Machinery(ACM)*, 3:184–195, 1960.

[CMRS55] J. Mc. Carthy, M. L. Minsky, N. Rochester, and C. E. Shanon. A proposal for the darmouth summer research project on artificial intelligence. Technical report, Darmouth, August 31 1955.

[DD87] H. Dreyfus and S. Dreyfus. *Mind over Machine*. The Free Press NewYork, 1987.

[Den71] Daniel C. Dennett. Intentional systems. *J. Phil.*, 68:87106, 1971.

[Den82] D. C. Dennett. *How to study consciousness empirically, or Nothing comes to mind*. Synthese 59, 1982.

[Den84] D. C. Dennett. Cognitive wheels: the frame problem of AI. In *Mind, Machines, and Evolution*, pages 129–151. Cambridge, University Press Cambridge, 1984.

[Den91] D. C. Dennett. *Consciousness Explained*. Boston MA: Little Brown, 1991.

[Dev61] G. C. Devol. Unimate robots. US. patent No.2,998,237, 1961.

[Elm90] J. Elman. Finding structure in time. *Cognitive Science*, 14:179–211, 1990.

[FB82] J. A. Feldman and D. H. Ballard. Connectionist models and their properties. *Cognitive Science*, 6:205–254, 1982.

[FP88] J. A. Fodor and W. Pylyshyn. Connectionism and cognitive architecture: A critical analysis. In Pinker and Mehler, editors, *Connections and Symbols*, pages 3–71. MIT press, 1988.

[GMV07] S. Giulio, G. Metta, and D. Vernon. The icub cognitive humanoid robot: An open-system research platform for enactive cognition. In Max Lungarella, Fumiya Iida, Josh Bongard, and Rolf Pfeifer, editors, *50 Years of Artificial Intelligence, volume 4850 of Lecture Notes in ComputerScience, Springer Berlin Heidelberg, Berlin and Heidelberg*, pages 358–369, 2007.

[Gra05] G. Granlund. *A cognitive vision architecture integrating neural networks with symbolic processing.* KI-Zeitschrift Knstliche Intelligenz, Special Issue on Cognitive Computer Vision, April 2005.

[Gro76] S. Grossberg. Adaptive pattern classification and universal recoding: I parallel development and coding of neural feature detector. *Biological Cybernetics*, 23:121–134, 1976.

[HML93] S. Huffman, C. Miller, and J. Laird. *Learning for instruction: a knowledge-level capability within a unified theory of cognition.* Proceedings of the 15th Annual Meeting of the Cognitive Science Society, 1993.

[Hop82] J. J. Hopfield. Neural network and physical system with emergent collective computational abilities. In *Proceedings of Natianal Academy of Sciences*, volume 79, pages 2554–2588, 1982.

[HP95] S. R. Hameroff and R. Penrose. Orchestrated reduction of quantum coherence in brain microtubules. *A model for consciousness Neural Network World*, 5(5):793–804, 1995.

[HP96] S. R. Hameroff and R. Penrose. *Orchestrated Reduction Of Quantum Coherence In Brain Microtubules: A Model For Consciousness?* MIT Press, 1996.

[HS86] G.E. Hinton and T. J. Sejnowski. Learning and relearning in boltzmann machine. In *Parallel Distributed processing:Exploration in Microstructure of Cognition,D. E. Rumellhart and J. L. McClelland Eds., Cambridge, MA*, pages 282–317. MIT press, 1986.

[Huf94] S. Huffman. *Instructable Autonomous Agents.* PhD. Thesis, 1994.

[Hur98] S. L. Hurley. *consciousness in Action*. Cambridge, Mass: Harvard University Press, 1998.

[JTLR93] R. Jones, M. Tambe, J. Laird, and P. Rosenbloom. Intelligent automated agents for flight training simulators. In *Proceedings of the Third Conference on Computer Generated Forces and Behavioral Representation*, 1993.

[Kit99] T. Kitamura. *Can a robot's adaptive behavior be animal-like without a learning algorithm?* IEEE Systems, Man, and Cybernetics Conference, Tokyo, 1999.

[KM97] D. Kieras and D. E. Meyer. An overview of the EPIC architecture for cognition and performance with application to human-computer interaction. *Human-Computer Interaction.*, 12:391–438, 1997.

[KMMS99] D. E. Kieras, D. E. Meyer, S. Mueller, and T. Seymour. Insights into working memory from the perspective of the EPIC architecture for modeling skilled perceptual-motor and cognitive human performance. In A. Miyake and P. Shah, editors, *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control*. Cambridge University Press, New York, 1999.

[Koh82] T. Kohenen. Self organized formation of topologically correct feature maps. *Biologicl Cybernetics*, 43:59–69, 1982.

[KON95] T. Kitamura, Y. Otsuka, and T. Nakao. *Imitation of animal behaviour with use of a model of consciouness behaviour relation for a small robot*. IEEE International Workshop on Robot and Human Communication, Tokyo, Japan, 1995.

[KWM97] D. E. Kieras, S. D. Wood, and D. E. Meyer. Predictive engineering models based on the EPIC architecture for a multimodal high-performance human-computer interaction task. *ACM Transactions on Computer-Human Interaction. 4*, 4:230–275, 1997.

[LA93] C. Lebiere and J. R. Anderson. A connectionist Implementation of the ACT-R production system. In *Proceedings of the Fifteenth Annual Conference of the Cognitive Science Society*, pages 635–640. Mahwah, NJ: Lawrence Erlbaum Associates, 1993.

[LCAD93] J. Laird, C. B. Congdon, E. Altmann, and R. Doorenboos. The soar user's manual version 6, 1993.

[LHH91] J. Laird, M. Hucka, and S. Huffman. *An analysis of Soar as an integrated architecture*. SIGART Bulletin 2, 1991.

[LHJ+90] R. Lewis, S. Huffman, B. John, J. Laird, J. Lehman, A. Newell., P. Rosenbloom, T. Simon, and S. Tessler. Soar as a unified theory of cognition: Spring 1990. In PA: Cognitive Science Society, editor, *Proceedings of the 12th Annual Conference of the Cognitive Science Society, Cambridge, MA. pp. 1035-1942. Pittsburgh*, pages 1035–1942, 1990.

[LLN91] J. Lehman, R. Lewis, and A. Newell. Integrating knowledge sources in language comprehension. In *Proceedings of the Thirteenth Annual Conference of the Cognitive Science Society. Pittsburgh*. PA: Cognitive Science Society, 1991.

[LMA+91] P. Langely, K. B. McKusick, J. A. Allen, W. F. Iba, and K. Thompson. *A design for the ICARUS Architecture*. SIGART Bulletin 2, 1991.

[LRN87] J. E. Laird, P. S. Rosenbloom, and A. Newell. Soar: An architecture for general intelligence. *Artificial Intelligence*, 33:1–64, 1987.

[Mat70] H. R. Maturana. *Biology of Cognition*. Univ. Illinois, Urbana, IL,Research Rep. BCL 90, 1970.

[McC81] J. L. McClelland. Retrieving general and specific information from stored knowledge of specifics. In *Proceedings of 3rd Annual Meeting of the Cognition Science Society*, pages 170–172, 1981.

[MD89] J. Moody and C. J. Darken. Fast learning in networks of locally tuned processing unit. *Neural Computation*, 1:281–294, 1989.

[Min67] M. Minsky. *Finite and Infinite Machine*. Prentice Hall, Englewood Cliffs, NJ, 1967.

[Min75] M. Minsky. A framework for representing knowledge. *The Psychology of Computer Vision(P. H. Winston,Ed) Mc Graw Hill*, pages 211–277, 1975.

[Min86] M. Minsky. *The Society of Mind*. Simon and Schuster, New York, 1986.

[MK97a] D. E. Meyer and D. E. Kieras. A computational theory of executive cognitive process and multiple task performance: Part1, basic mechanism. *Psychological Review*, 104:3–65, 1997.

[MK97b] D. E. Meyer and D. E. Kieras. A computational theory of executive cognitive process and multiple task performance: Part2, accounts of psychological refractory-period phenomena. *Psychological Review*, 104:749–791, 1997.

[MK99] D. E. Meyer and D. E. Kieras. Precis to a practical unified theory of cognition and action: Some lessons from computational modeling of human multiple-task performance. In D. Gopher and A. Koriat, editors, *Attention and Performance XVII*, page 17. M, -88). Cambridge, MA, 1999.

[MKL+95] D. E. Meyer, D. E. Kieras, E. Lauber, E. Schumacher, J. Glass, E. Zurbriggen, L. Gmeindl, and D. Apfelblat. Adaptive executive control: Flexible multiple-task performance without pervasive immutable response-selection bottlenecks. *Acta Psychologica*, 90:163–190, 1995.

[MP43] W. S. McCulloch and W. Pitts. A logical calculas of ideas immanent in nervous activity. *Bull. Math. Biophys*, 5:115–113, 1943.

[MP69] M. Minsky and S. Papert. *Perceptrons: An introduction to Computational Geometry*. Cambridge, MA: MIT press, 1969.

[MV80] H. R. Maturana and F. J. Varela. *Autopoiesis and Cognition*. The realization of the living, Ser. Boston Studies on the philosophy of Science.Dordrecht, Holland : D. Reidel Publishing Company, 1980.

[MV87] H. R. Maturana and F. J. Varela. *The Tree of knowledge: The Biological roots of Human Understanding*. Boston New Science Library, 1987.

[New90] A. Newell. *Unified Theories of Cognition*. Cambridge MA, Harvard University Press, 1990.

[Noe05] A. Noe. *Action in Perception*. 289 MIT Press, 2005.

[NS72] A. Newell and H. A. Simon. *Human Problem Solving*. Prentice Hall, Englewood Cliffs, NJ, 1972.

[NS76] A. Newell and H. A. Simon. Computer science as emperical enquiry:symbol and search. *Communication of the Association for Computing Machinery(ACM)*, 3(19):113–126, 1976.

[NSS59] A. Newell, J. C. Shaw, and H. A. Simon. Report on general problem solving program. In *Proceedings of the International Conference on Information Processing*, pages 256–264, Paris, 1959.

[OA01] J. K. O'Regan and A.Noe. A sensorimotor account of visual consciousness. *Behavioral and Brain Sciences*, 11(5):939–973, 2001.

[Res01] S. Restivo. Bringing up and booting up: social theory and the emergence of socially intelligent robots. *IEEE*, 4:2110–2117, 2001.

[RLN93] P. Rosenbloom, J. Laird, and A. Newell. *ed.* The Soar Papers: Research on Integrated Intelligence, 1993.

[RLNM91] P. Rosenbloom, J. Laird, A. Newell, and R. McCarl. A preliminary analysis of the Soar architecture as a basis for general intelligence. *Artificial Intelligence*, 47:289–235, 1991.

[RMG86] D. E. Rumelhart, J. L. McClelland, and PDP Research Group. Parallel distributed processing: Explorations in the microstructure of cognitions. In *Vol 1: Foundations; Vol 2: Psychological and Biological models*. MIT Press, 1986.

[Ros58] F. Rosenblatt. The perceptron: A probablistic model for information storage organization in the brain. *Psy. Rev.*, 65:386–408, 1958.

[SA77] R. C. Schank and R. P. Abelson. Scripts , plans, goals and understanding: an inquiry into human structures. *Hillslade, N J:Erlbaum*, page 248, 1977.

[SA97] R. Sun and F. Alexandre. *Connectionist symbolic integration.* Hillslade,NJ:Erlbaum, 1997.

[Sam59] A. L. Samuel. Some studies in machine learing using the game of checkers. *IBM journal*, 3(3):210–229, 1959.

[SB94] R. Sun and L. Brookman. *Computational Architectures Integrating Neural and Symbolic Process.* Kluwer, Academic Publisher, 1994.

[SLG+99] E. H. Schumacher, E. J. Lauber, J. M. B. Glass, E. L. Zurbriggen, L. Gmeindl, D. E. Kieras, and D. E. Meyer. Concurrent response-selection processes in dual-task performance: Evidence for adaptive executive control of task scheduling. *Journal of Experimental Psychology: Human Perception and Performance*, 25:1–24, 1999.

[Smo87] P. Smolensky. On the proper treatment of connectionism. *Behavioral and Brain Science*, 11(1):1–74, 1987.

[SPS01] R. Sun, T. Peterson, and C. Sessions. *Beyond simple rule extraction: acquiring planning knowledge from neural networks*. Proceedings of WIRN'01, Salermo, Italy, 2001.

[Str52] C. Strachey. Logical or non mathematical programmes. In *Proceedings of the Association for Computing Machinery Meeting, Association of Computing Machinery*, pages 46–59, Newyork, 1952. ACM'52.

[Sun94] R. Sun. *Integrating Rules and Connectionism for Robust Reasoning*. John Willey and Sons NewYork, NY 1994, 1994.

[Sun95] R. Sun. Robust reasoning: Integrating rule based and similarity based reasoning. *Artificial Intelligence*, 75:241–295, 1995.

[Sun06] R. Sun. *The CLARION cognitive architecture: Extending cognitive modeling to social simulation*. Cambridge University Press, New York, 2006.

[Sun07] R. Sun. *The motivational and metacognitive control in CLARION*. Modeling Integrated Cognitive Systems In: W. Gray, 2007.

[Sun08] R. Sun. Introduction to computational cognitive modeling. In *Cambridge handbook of computational psychology*, page 319. Cambridge University Press, New York, 2008.

[Tho07] E. Thompson. *Mind in Life Biology, Phenomenology and the Sciences of Mind*. (1)568 Harvard University Press, 2007.

[Tur50] A. M. Turing. Computing machinery and intelligence. *Mind*, 59:433–460, 1950.

[Wei66] J. Weizenbaum. A computer program for the study of natural language communication between man and machine. *Communications of the Association for Computing Machinery(ACM)*, 9(1):36–55, 1966.

[WF86] D. Waltz and J. Feldman. *Connectionist models and their implications*. Albex, Norward NJ, 1986, 1986.